Construction and Building Materials 52 (2014) 428–436

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Wood as a building material in the light of environmental assessment of full life cycle of four buildings

Grzegorz Pajchrowski [a,*], Andrzej Noskowiak [a], Anna Lewandowska [b], Wladysław Strykowski [a]

[a] Wood Technology Institute, ul. Winiarska 1, 60-654 Poznan, Poland
[b] Faculty of Commodity Science, Poznan University of Economics, al. Niepodległości 10, 61-875 Poznan, Poland

HIGHLIGHTS

- LCA study of four functionally equivalent single-family houses were performed.
- As a renewable material, wood is ideal for sustainable buildings.
- Benefits of using wood appear in almost all stages of buildings' life cycles.

ARTICLE INFO

Article history:
Received 5 July 2013
Received in revised form 13 November 2013
Accepted 19 November 2013
Available online 10 December 2013

Keywords:
Buildings
Life cycle
Wood
Environmental impact

ABSTRACT

This paper presents the results of the research project financed by the Polish Ministry of Science and Higher Education (N N309 078138) and coordinated by the Wood Technology Institute in Poznan. One of the key points of this project was LCA study of four detached single-family dwellings in the context of intensification of wood usage. Four functionally equivalent buildings with different material structure, building technology and energy standards have been subjected to Life Cycle Assessment (LCA) environmental impact analysis. The study has taken into account a full life cycle of the buildings, including the following stages: production of building materials, prefabrication, transport to the building site, building, use, demolition, transport of waste and final disposal of waste. Wood and wood-based materials, are the only ones from among the analysed building materials, that have shown an environmental benefit both from the "cradle-to-gate" (stage 1) and "gate-to-grave/reincarnation" (stage 7) perspective.

1. Introduction

In EU countries, despite the traditions of building with stone and concrete, an increased interest with wood and wood-based materials can be seen. The possibilities of using wood in the building industry are numerous. One of the more prominent directions, is the production of light and strong construction elements. Wooden buildings can be seen more and more often in the landscape of Polish cities, towns and villages. Wood facades are becoming a visible sign of an increased popularity of using wood in the building industry. Special aesthetic and technical qualities of wood favour an increasing dominance of this material in the production of floors and decks. More and more interior architects choose wood as an attractive material for the production of interior woodwork and furniture. Solid wood and wood-based materials are perfectly suited for building single-family detached houses featuring either traditional or modern architecture. In the last couple of years, more and more housing estates have been built in Poland, including multi-dwelling units whose walls, ceilings and roofs have been prefabricated from wood and wood-based panels. Designers of aquatic centres, sports arenas, entertainment arenas, churches, hotels and inns are increasingly more keen on using this material.

The role of wood in the modern economy is becoming more and more important, which results from the fact that it combines many qualities that are crucial from the ecological and technological point of view, among which we can include [1–7]:

- it is both light and mechanically strong,
- it has a good thermal conductivity coefficient,
- it is warm to the touch,
- it does not change its dimensions when temperature changes,
- it deadens noise well,
- it is resistant to the effects of destructive chemical substances,
- before it gives in to the destructive forces, it issues a "warning" by creaking, providing time for evacuation,
- it absorbs the humidity in highly humid conditions, and releases it in very dry conditions, positively influencing the microclimate of rooms,

* Corresponding author. Tel.: +48 618492412.
E-mail address: g_pajchrowski@itd.poznan.pl (G. Pajchrowski).

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.11.066

- it is both durable and resistant to the effect of destructive biological factors,
- it is a renewable material,
- it shows a beneficial, carbon balance and embodied energy indicator, in comparison to other building materials,
- it can be easily worked mechanically and it can be modified, as well as relatively easily and inexpensively transformed into other useful building, insulation or finishing materials.

The opponents of using wood in the building industry mention arguments concerning weaknesses of wood as the building material, which include: flammability, relatively low durability, high hygroscopicity and susceptibility to the effect of fungi, moulds and insects. However, the majority of these issues can currently be overcome by using, e.g. appropriate impregnates and preservatives.

Within the context of the sustainable development, the ecological aspects of building materials and entire buildings has become increasingly more important. The environmental assessments carried out within the scope of the building industry can pertain to three types of objects: only Building Materials (BM) [8–11], Component Combination (CC) [12–14] or the Whole Process of the Construction (WPC) [15,16]. Such studies can incorporate various scopes or include only a part of the life cycle, e.g. the production of building materials (cradle-to-gate) or the disposal of building waste (gate-to-grave/reincarnation), but they can also assume the perspective of a full life cycle. In literature we can find analyses of environmental impact dedicated to wood treated as both a building material [17,18] and waste [19]. Also, certain individual publications can be found concerning the environmental assessment of wood as a building material carried out in the light of full life cycles of buildings [20].

The main goal of the study presented in this paper was to analyse and assess potential environmental advantages of using wood in construction of houses. Making by one group of researchers a comparison between four functionally equivalent houses can be recognised as a strong point of the study, because the initial assumptions, data quality, system boundaries were similar for all analysed objects. These buildings were assumed to have the same energy requirements for 100 years use stage in corresponding pairs (conventional and passive). Having the same energy requirements, usage of different construction materials can differentiate environmental burdens arising from the other stages, mainly from production of building materials and final disposal of demolition waste. It was assumed that wood, as a renewable and carbon neutral material, might diminish these burdens in the most significant way.

2. LCA study

Four model single-family residential buildings for a 4-person family with the usable area of 98.04 m^2 have constituted the objects of the study. These buildings differed in material structure, building technology and the energy standard. The following objects have been analysed: a conventional masonry building (A1), a passive masonry building (A2), a conventional wooden building (B1) and a passive wooden building (B2) (Fig. 1). The term wooden building should be understood as a building with maximisation of the use of wood everywhere where it is technologically and functionally justified. All analysed objects constituted single-storey buildings with the following functional program: hall, toilet, living room with a dining area, kitchen, 2-person bedroom, two 1-person rooms, bathroom and laundry room. A separate architectonic design has been prepared for each of the above mentioned buildings. The material use, operational parameters, installations and the use of energy carriers have been calculated individually for each of the buildings, however, in the case of variants A2 and B2 this has been done while taking into account the requirements for passive buildings [21,22]. The buildings have been situated in such a way in relation to the sides of the world so as to maximise the benefit from the solar radiation (large windows in the south wall), which is of special importance in the case of passive buildings.

Buildings serve various functions, among which we can include: occupancy, shielding, hygienic, aesthetic and construction function. Within the scope of the conducted studies, the occupancy and shielding functions have been assumed to constitute the main functions, and on such a basis the functional unit of the studies has been defined: *ensuring 98.04 m^2 of residential area fit to be used for a period of 100 years and ensuring the occupants and items protection from the harmful effect of external factors.* Table 1 provides the characteristics of the construction system and the method of foundation of the analysed buildings. All the analysed buildings have load-bearing structure in a longitudinal arrangement. The masonry buildings are assumed to use load-bearing wall built in a single-layer SOLBET masonry technology in a case of conventional house (A1) and in a double-layer masonry technology in a case of passive house (A2). The wooden buildings (B1, B2) are designed as having load-bearing walls built using a light framework. Traditional wood roof with a collar beam are assumed for masonry buildings while ceiling and pitched roof constructed using lattice trusses are destined to wooden houses. The differences lie also in a construction of foundations (Table 1).

2.1. Material structure of the analysed buildings

The division of the selected buildings into masonry (A1, A2) and wooden (B1, B2), and into conventional (A1, B1) and passive (A2, B2) required architects to assume different design solutions that resulted in a varied material structure of analogous house modules. Table 2 shows individual modules of the analysed buildings according to the weight of building materials within their scope. Table 2 presents the "gross" values constituting the weight of materials delivered directly to the building site or for prefabrication (namely the material loss occurring during the transport and building processes performed on the building site have been taken into account). As Table 2 shows, building materials necessary for constructing masonry buildings weigh 217,986.7 kg (A1) and 244,282.3 kg (A2) and are considerably heavier than materials required for constructing wooden buildings 150,993.8 kg (B1) and 91,623.8 kg (B2). The passive masonry building (A2) as "the heaviest" was 12% heavier than the conventional masonry building (A1),

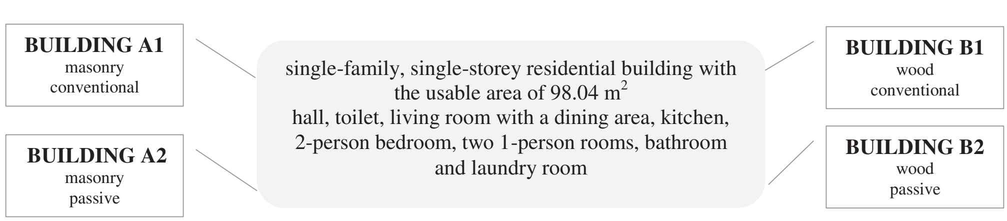

Fig. 1. Variants of four model buildings selected for analysis. *Source:* [23].